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A Review on Recent Advances and Challenges of Fuel Cell Electric Vehicles

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Reviews

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ABSTRACT

Fuel cell systems in electric vehicles are environmentally friendly and therefore they are being used especially in heavy-duty vehicles. Determining the critical elements of this promising system increases its performance and reliability, facilitating the design process and guiding Research and Development processes. In this study, reference studies were reviewed for general difficulties and performance-enhancing tips for fuel-cell electric vehicles. A total of 27 fuel cell system performance tips have been outlined along with 5 vehicle topology assessment studies. Also, total 19 different current studies and projects were reviewed. The results of this study showed that the fuel cell system has significant potential with small improvements. Factors such as temperature, humidity, material type, fuel cell stack, and air rate are found to be critical variables in fuel cell systems. Besides the variables, battery, supercapacitor, and hydrogen storage in the vehicle topology are significant factors for fuel-cell electric vehicles.

Yakıt Hücreli Elektrikli Araçların Zorlukları ve Son Gelişmeleri üzerine Derleme

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ÖZ

Elektrikli araçlarda yakıt pili sistemleri çevre dostudur ve bu nedenle özellikle ağır hizmet araçlarında kullanılmaktadır. Gelecek vadeden bu sistemin kritik unsurlarının belirlenmesi, sistemin etkinliğini ve güvenilirliğini artırmakta, tasarım sürecini kolaylaştırmakta ve Ar-Ge süreçlerine yön vermektedir. Bu çalışmada, yakıt hücreli elektrikli araçlar için genel zorluklar ve performans artırıcı ipuçları için referans çalışmalar gözden geçirilmiştir. 5 araç topolojisi değerlendirmesiyle birlikte toplam 36 yakıt hücresi performans iyileştirici tavsiye ana hatlarıyla belirtilmiştir. Ayrıca toplam 19 farklı güncel çalışma ve proje incelenmiştir. Bu çalışmanın sonuçları, yakıt pili sisteminin küçük iyileştirmelerle önemli bir potansiyele sahip olduğunu göstermiştir. Yakıt hücresi sistemlerinde sıcaklık, nem, malzeme tipi, yakıt hücresi yığını ve hava hızı gibi faktörlerin kritik değişkenler olduğu bulunmuştur. Araç topolojisindeki değişkenlerin yanı sıra pil, süper kapasitör ve hidrojen depolama, yakıt hücreli elektrikli araçlar için önemli faktörlerdir.

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1. Introduction

The rise in electric demand and greenhouse gas volume drives countries into finding alternatives. Fossil fuels are the main environmental contaminants and cannot provide a sustainable future (Yavaş et al., 2022). When compared to hydrogen sources, fossil fuel sources' fuel efficiency is low and CO_2 emission is much high (Kilic and Altun, 2022). That is why approximately all research projects are focused on renewable energy sources. Fuel cell electric vehicles, besides being environmentally friendly, silent, and useful vehicle systems, also have the advantage of fast refuelling and long range compared to battery electric vehicles.

Until recent years, many automobile brands have worked on fuel cell vehicles and the developments in this field continue. Along with the advantages of the fuel cell, there are also situations that need to be considered for its effective use. In 2022, approximately 1300 academic studies covering various sub-topics on fuel cells have been published (WebofScience, 2023). In this work, among the mentioned publications, the problems, suggestions, and topology comparisons on fuel cell vehicles are searched and important parts are explained. It aimed to reveal a guiding study in fuel cell electric vehicle design by observing technical problems and solutions.

2. Fuel Cell

In hydrogen-based electric vehicles, the fuel cell provides electricity generation through redox reactions.

Fuel cell is working on catalysing process. The electrons and protons of fuel are separated when the fuel contact with the catalyser. Electrons are canalized to electronic circuit. Protons pass through the catalyst and meet the oxygen willing to hydrogen. While this meeting electrons come from the circuit and join to hydrogen again. Oxygen and hydrogen product the output of this system that is water. Basic illustration of fuel cell working principle was shared in Figure 1.

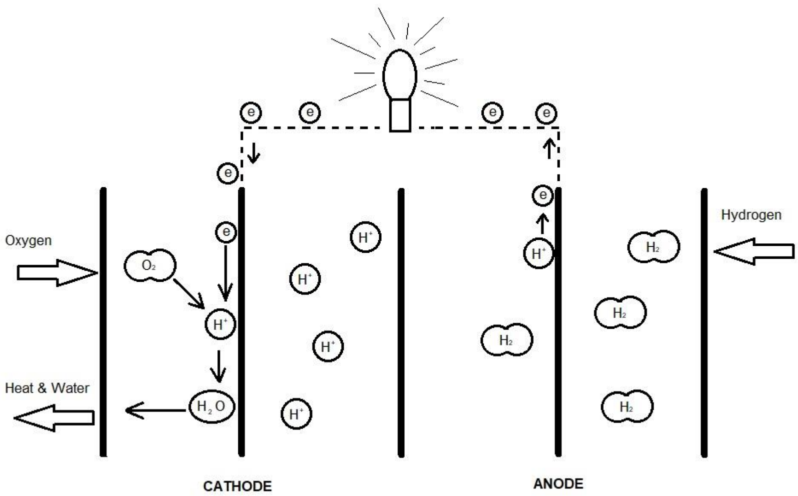


Figure 1. Fuel cell system proton exchange membrane working principle (U.S. Department of Energy, 2015)

Although the target is the same, there is more than one fuel cell module as the working principle. The basic fuel cell types and their characteristics are listed in table 1 below.

Apart from the basic fuel cell types listed in Table 1 with their specifications, there are also different fuel cell types. Table 2 shows the characteristics of other fuel cell types.

Table 1. Basic fuel cell types and characteristics (Üçgül and Şenol, 2006; Çakar and Türkoğlu, 2011)

Fuel Cell Type	Electrolyte	Load	Working Temperature (°C)	Catalyst	Efficiency (%)	Battery Base	Fuel Type
Polymer Electrolyte Fuel Cell (PEMFC)	Polymer Membrane	H^+	50 - 100	Platinum	40 – 55	Carbon	H_2, methanol
Alkaline Fuel Cell (AFC)	Potassium Hydroxide (liquid KOH)	OH-	120 – 250	Platinum	45 – 60	Carbon	H_2
Phosphoric Acid Fuel Cell (PAFC)	Phosphoric Acid (H_3PO_4)	H+	150 – 220	Platinum	37 – 42	Carbon	H_2, methanol
Molten Carbonate Fuel Cell (MCFC)	Molten Carbonate	CO_3^{-2}	600 – 700	Nickel	55 – 65	Stainless Steel	H_2, Natural Gas
Solid Oxide Fuel Cell (SOFC)	Ceramic (ZrO2, CeO_2, Bi_2O_3)	O^{-2}	650 – 1000	No Catalyst	55 – 70	Ceramic	H_2, CH_4, Natural Gas

Table 2. Other fuel cell types and characteristics (Ogungbemi et al., 2019)

Fuel Cell Type	Efficacy (%)	Working Temperature (°C)	Load	Fuel Type
Low Temperature PEM	40 – 60	60 – 80	H+	H_2
High Temperature PEM	50 – 60	110 – 180	H+	H_2
Direct methanol fuel cell (DMFC)	35 – 60	Environment – 110	H+	Liquid Methanol-water mix
Direct ethanol fuel cell (DEFC)	20 – 40	Environment – 120	H+	Liquid Ethanol-water mix
Proton ceramic fuel cell (PCFC)	55 – 65	700 – 750	H+	methane
Zinc-Air fuel cell (ZAFC)	30 – 50	Sub-zero – 60	OH-	Zinc
Direct borohydride fuel cell (DBFC)	40 – 50	20 – 85	Na+	Sodium Borohydride
Direct formic acid fuel cell (DFAFC)	30 – 50	30 – 60	H+	Liquid Formic Acid

Direct carbon fuel cell (DCFC)	70 – 90	600 – 1000	O_2^-	Solid Carbon
Enzymatic fuel cell (BFC)	30	20 – 40	H+	Glucose
Microbial fuel cell (MFC)	15 – 65	20 – 60		Organic matter

Among the fuel cells showed in table 1 – 2, DMFC, PEMFC, AFC and PAFC are expressed as low operating temperature fuel cells, and MCFC and SOFC are expressed as high operating temperature fuel cells (Tie and Tan, 2013).

The advantages of the proton exchange membrane system are that it works between 70 – 90 ^oC, it is widely used, and it works silently and without vibration. Requirements such as deionized water, platinum, water collector, membrane maintenance can be listed as disadvantages (Nguyen and Lindström, 2017). Proton exchange membrane fuel cells are more suitable to be preferred over other types due to their high power density and low corrosion formation. (Baba et al., 2021)

3. Hydrogen Production and Storage

Since the hydrogen has natural characteristic, it can be found and can be produced from several sources. Although the most-known production method is electrolysis for hydrogen production but there are several hydrogen production method apart from electrolysis. The method described by Dinçer and Acar (Dincer and Acar, 2014) regarding hydrogen production is given below.

- Electrolysis
- Plasma Arc Decomposition
- Water Thermolysis
- Thermochemical Water Splitting
- Thermochemical Conversion of Biomass, Gasification, and Biofuel Reforming
- Photovoltaic Electrolysis, Photo catalysis, and Photo electrochemical Method
- Dark Fermentation
- High Temperature Electrolysis
- Hybrid Thermochemical Cycles
- Coal Gasification
- Fossil Fuel Reforming
- Bio photolysis and Photo fermentation
- Artificial Photosynthesis
- Photo electrolysis

After the production of hydrogen, which is necessary for the production of electrical energy, the most important issue is its easy and effective storage. In the production of hydrogen, steam, gas and electrolysis methods are preferred from basic sources such as natural gas, bioethanol, coal, and biomass (Baba et al., 2021). The storage method to be used for hydrogen must be able to preserve the matter it contains in a ready-to-use condition under desired conditions. Hydrogen storage methods frequently encountered in the literature (Üçgül and Şenol, 2006; Tie and Tan, 2013; Abe et al., 2019) are shared below.

- Compression into tube
- Cryogenic cooling (liquidification at -253 ^oC)
- Hydrogen absorbers (absorption by temperature and pressure)

The most economical of these three methods is to store hydrogen as pressurized gas, but the amount of hydrogen stored is insufficient due to the low energy density of hydrogen and the necessity of making pressure vessels in certain sizes depending on the vehicle dimensions (Ucgul and Şenol, 2006). Liquid hydrogen must be stored below -250 ^oC. Even well-insulated storage cannot maintain this temperature without external cooling. In this case, 1-3 % leakage will occur per day. This propagation is not considered dangerous as controlled oxidation with catalysts is possible. Alternatives for hydrogen storage are compared in Table 3.

Table 3. Hydrogen storage technologies (Nguyen and Lindström, 2017)

Storage Type	Advantage	Disadvantage
Compressed gas cylinder	Known as until 200 bar Low cost Generally available	Storage capacity is lower than 700 bar High pressure storages are in development
Liquid tanks	Well-known technology Good storage density	Need low temperature High cost Hydrogen lost by vaporization
Metal hydrides	Solid storage Variable dimensions Safe Thermal outputs can be used in sub-systems	Heavy Gets worse over time Expensive
Carbon structures	High storage density Light and cheap	Not understood and developed

In order to overcome the lack of resources for hydrogen storage, it can be a good alternative to operate the module, which acts as a fuel cell while driving, in the electrolysis mode in the parking position. However, the need for a battery at the time of start-up in a cold environment, the inability to produce a long range despite electrolysis for a long time, the need for storage show the negative sides of this system. (Borroni-Bird, 1996)

One of the safest methods is to store hydrogen with metal hydride. Gaseous hydrogen penetrates into the lattice-shaped internal structures of light-mass hydride metals or their alloys and binds to various parts of the crystal structure, and when the hydrides are heated, the absorbed hydrogen is released (Ucgul and Şenol, 2006). Different porous metal alloys should be used in this storage. The main disadvantage of this method is the weight of the metal hydride required to store the required fuel (longer than 320 km). Some alloys reach up to 1250 kg to store 15 kg of hydrogen. Another disadvantage is that some materials used in the alloy are flammable.

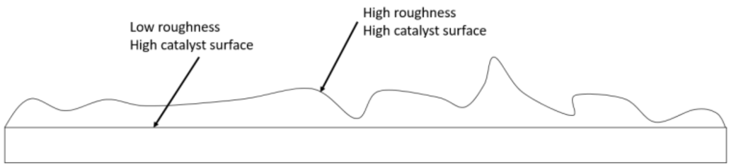
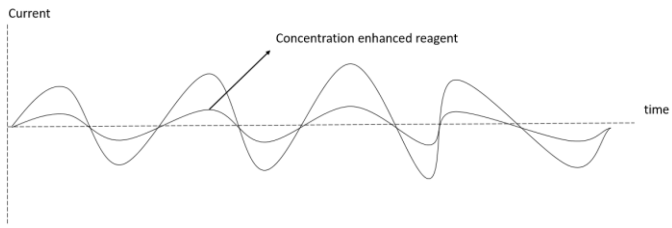
In addition to obtaining hydrogen in an environment outside the vehicle and transporting it on the vehicle while driving, it is also a good alternative to obtain hydrogen from a source while driving.

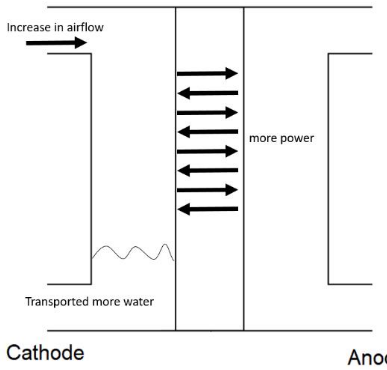
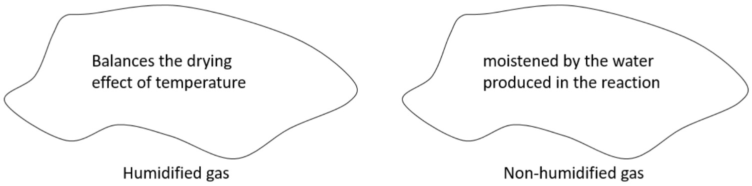
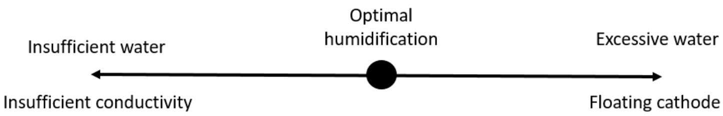
Obtaining hydrogen via on board equipment has the potential to eliminate the need for costly, heavy and bulky storage tanks. One of the forms in which hydrogen can be obtained is methanol. It is profitable to obtain hydrogen by cracking methanol, but the CO content in the cracked gas is very high. However, in this case, poisoning of the anode electrode of the fuel cell becomes easier. The methanol cracking process is an endothermic reaction and heat devices are required, in which case hydrogen production becomes complicated and also affects the take-off speed of the fuel cell vehicle. The partial oxidation of methanol enables rapid production of hydrogen and its performance is high, but the hydrogen content in the reaction gas is not very high. The density of hydrogen in the gas mixture and fuel cell decreases due to oxidation of air. (Shusheng et al. 2020)

4. Fuel Cell Performance Enhancement Tips

In many fuel cell applications, as in every system, problems arise. Determining the problems in terms of technical and cost will provide great convenience in increasing the system performance. The problems and recommendations seen in the various references reviewed are shared in table 4 below.

Table 4. Fuel cell system performance enhancer tips

No	Tips	Reference
1	Increasing the cell temperature	(Dicks and Rand, 2018; Alaswad et al., 2021)
2	Using a catalyst for enhance the reaction kinetics	(Dicks and Rand, 2018; Alaswad et al., 2021)
3		(Dicks and Rand, 2018; Alaswad et al., 2021)
4		(Dicks and Rand, 2018; Alaswad et al., 2021)
5	Raising the pressure of the reagents with high concentration.	(Alaswad et al., 2021)
6	Use of electrodes with the highest conductivity	(Alaswad et al., 2021)
7	Design optimization and material selection for bipolar plate	(Alaswad et al., 2021)
8	Making the membrane as thin as possible	(Alaswad et al., 2021)
9	Increasing the humidity of the membrane	(Alaswad et al., 2021)

10		(Alaswad et al., 2021)
11		(Alaswad et al., 2021)
12		(Alaswad et al., 2021)
13	Irregular (uncontrolled) temperature will create an electrochemical reaction in different regions, resulting in a decrease in stability and durability.	(Vichard et al., 2021)
14	Poor water management can cause the membrane to dry out, expands the resistant surface, and cause cracks. Air filter in bad condition can cause poisoning by contaminants.	(Vichard et al., 2021)
15	When the water content is high, catalyst aggregation due to dissolution, agglomeration, and redeposition results in reduced catalyst layer surface areas.	(Tanaka et al., 2020)
16	For the power control of the fuel cell system, the air mass flow rate and pressure on the cathode side can be controlled by the compressor and the exhaust valve, the hydrogen pressure on the anode side can be regulated by the hydrogen injector.	(Gao et al., 2019)
17	Factors such as impurity and hydrogen peroxide accelerate the aging of the membrane and cause the membrane thickness to decrease. In addition, the use of iron-based materials in the separator and the accumulation of water in the separator channels cause corrosion of the iron, accelerates the chemical degradation of the contact area of the separator.	(Gao et al., 2019)
18	Impurities such as sulphur-based and nitrogen-based gases affect fuel cell performance. These impurities can be specified as H_2S, SO_2, NO_2, NH_3. Geographic conditions and climatic conditions affect the density of impurities.	(Gao et al., 2019)
19	Thanks to the coating of the hydrophobic gas diffusion layer with the hydrophilic micro porous layer, the resistance of the membrane is reduced without humidification and the water retention at the interface of the catalyst and the microporous layer thickens.	(Ogungbemi et al., 2021)
20	Zig-Zag flow model shows better cooling performance than straight flow channel.	(Ogungbemi et al., 2021)
21	Graphen coated samples have better corrosion resistance, and electric conductivity than uncoated samples.	(Ogungbemi et al., 2021)
22	Keeping warm and melting/heating source methods are recommended for fast start-up and icing problems.	(Gao et al., 2019)

23	For cost reduction, low value metal catalysts such as metal oxygen composition, organometallic macrocyclic compounds and transition phase metal sulphides can be used at the cathode, while calcium doped metal oxides can be used in carbide, non-platinum alloys as anode catalysts.	(Shusheng et al., 2020)
24	Reducing the use of platinum for cost reduction can be made possible by producing electrodes with a lower platinum content or replacing platinum with non-precious metals.	(Shusheng et al., 2020)
25	Composite membranes are suitable for automotive applications as they have a wide operating temperature range above 95 °C. Composite fuel cells give 11% more voltage at 95 °C when dry hydrogen and air materials are used.	(Ogungbemi et al., 2019)
26	Centrifugal and Roots compressors are the most suitable for fuel cell application for pressurization. They are smaller and less expensive than screw and scroll compressors and help reduce the weight and cost of PEM fuel cell vehicles already increasing with the use of platinum.	(Kerviel et al., 2018)
27	It has been observed that the use of turbines with the compressor reduces the power required by the air supply system by an average of 45.8%. Also, changing the maximum pressure ratio from 2.8 bar to 4.0 bar reduced the number of cells required to achieve the same output power by 12.5%.	(Kerviel et al., 2018)

5. Vehicle Topology Comparisons in Fuel Cell Electric Vehicles

Solving cell-based or source-based technical issues in fuel cell electric vehicles provides overall performance improvement. To be competitive, a fuel cell electric vehicle has 25 – 30% more efficient than a gasoline car (Granovskii et al., 2006). Efficaciousness can be enhanced by local improvements that affect global improvement, and component placement (topology) for global improvement also affects performance and consumption. When the basic propulsion system of fuel cell vehicles is examined, elements such as fuel cell module, battery, hydrogen storage, e-motor and transmission are seen.

Sarioglu et.al. (Sarioglu et al., 2014) studied on vehicle topology comparison. Their work focused on mainly 0-100 km/h acceleration, maximum speed, gradability at 60 km/h, hydrogen consumption, driving range, total and powertrain weight – cost. 4 different powertrain topology was modelled and compared in same driving profile. Topology examples and their effective subjects can be seen in figure 2. After driving cycles, the topology C was found to be the most suitable layout as it offers the lowest energy consumption as well as the expected ride comfort.

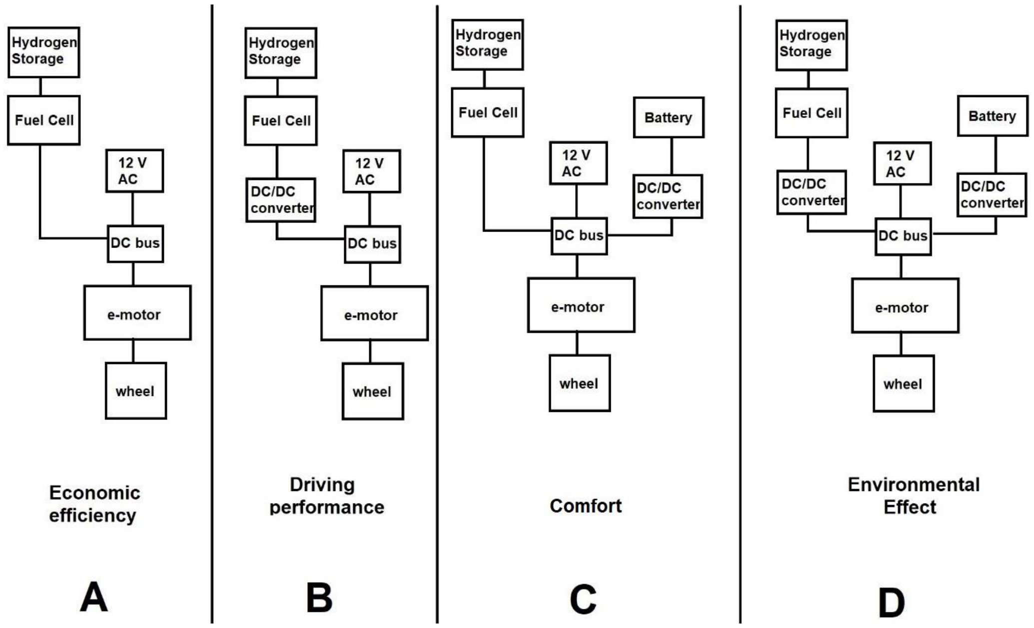


Figure 2. General topology examples and their effects (Granovskii et al., 2006)

Gao et. al. (Gao et al., 2016) studied on 2 different vehicle topology. When compared the 2 different vehicle topology, vehicle A reached to 50 km/h in 20,5 second with 18% grade and vehicle B reached to 50 km/h in 12,8 second with same grade. General lay out and technical specifications was shared in table 5.

Table 5. Fuel cell vehicle topology specifications (Gao et al., 2016)

Parameters	Powertrain A	Powertrain B
Fuel Cell	PEM 50 kW 517 – 350 V Efficiency 62,17%	PEM 50 kW 590 – 406 V Efficiency 57,93%
DC/DC converter	400 V input 60 kW Efficiency 94,6%	400 V input 60 kW Efficiency 97,16%
Battery	$LiMn_2O_4$ 175 Ah 405 – 260 V 870 W/kg at 50% SoC	$LiMn_2O_4$ 175 Ah 405 – 260 V 870 W/kg at 50% SoC
Motor	IM 100 kW 531 Nm 6000 rpm Efficiency 87,28%	PMSM 80 kW 350 Nm 6300 rpm Efficiency 90,97%
Reducer	1,86 ratio	13,92 ratio
Differential	6,2 ratio	-

Ahmadi et.al. (Ahmadi et al., 2018) studied on a hybrid fuel cell electric vehicle to obtain the required power for specified grade and speed. The vehicle model in this investigation has a fuzzy logic power sharing controller that decides between ultracapacitor, battery and fuel cell. Vehicle model has 1500 kg GVW, PEM type fuel cell module, ACIM 50 kW motor, 180 W/kg lead-acid batteries, 23000 W/kg ultra capacitor. General topology was showed in figure 3. This model needed 60.56 kW for reach to 100 km/h in 12 second and 72.44 kW for the same target with 5% grade.

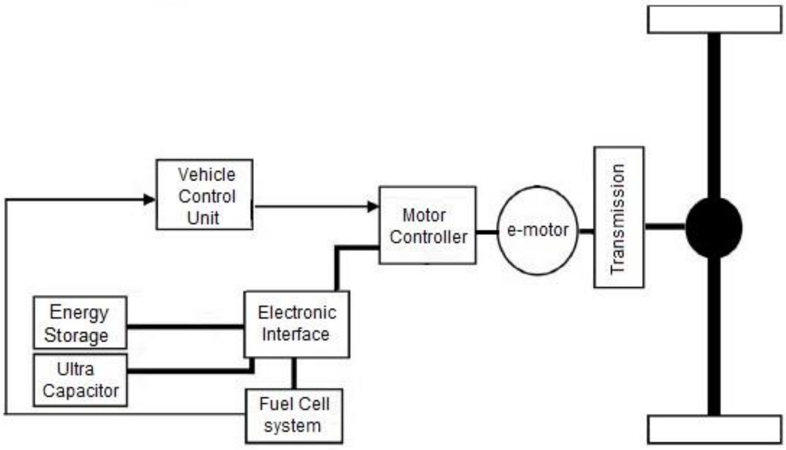


Figure 3. Fuel Cell hybrid electric vehicle topology (Ahmadi et al. 2018)

Nguyen and Lindström (Nguyen and Lindström, 2017) compared 3 different fuel cell electric truck topologies. The truck was modelled by adhering to various conditions and regulations related to temperature, fuel cell, tank, filling system. Among the shared layout types in Figure 4, topology A uses the fuel cell as the main power source. The range is 300% better and around 50% lighter than battery electric vehicles. In this configuration it has the most hydrogen capacity and can offer the best range. The topology B uses the battery as the main power source. The fuel cell is used as a range extender and the battery has a better range than electric vehicles. The battery is ideal for its projected route as it stops and starts in frequent and busy environments affected by topology. The topology C refers to the situation where hydrogen tanks cannot be placed behind the cabin. This configuration gives the shortest range. In this reference, it was decided that the back of the cabin was the most suitable place, based on the information obtained from the decision matrix regarding the positioning of the Hydrogen tanks. 300 kW was chosen to extend the life cycle of fuel cells, but since the cabin cooling power is too low for a 300 kW fuel cell, 200 kW fuel cell was preferred instead.

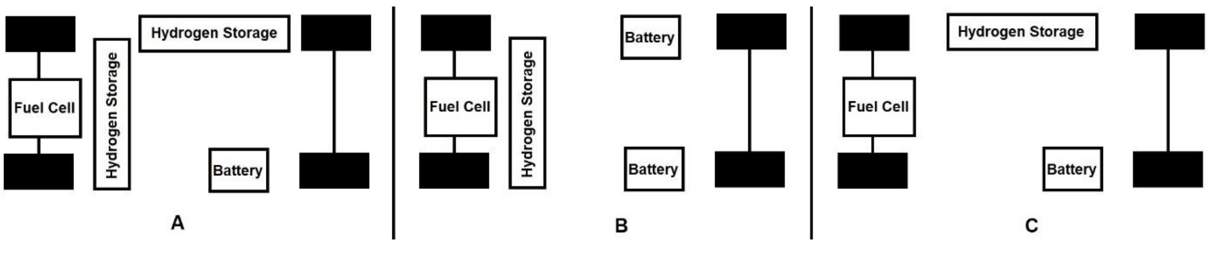


Figure 4. Fuel cell electric truck topologies (Nguyen and Lindström, 2017)

Xun et.al. (Xun et al., 2018) studied on comparison between 6 different fuel cell electric vehicle topologies. 6 different topologies were shared in figure 5. Each topology has a basic fuel cell, DC/AC inverter and electric motor. On the other hand, different topologies were obtained and evaluated by changing the number and placement of DC/DC converter, battery and supercapacitor. The simulation results showed that the hybridization of the fuel cell and supercapacitor has better performance of the fuel cell with the help of the supercapacitor, since high charge and discharge current can be obtained with the supercapacitor. Also, the supercapacitor can handle peaks in the required drive power, which makes the power supplied by the fuel cell flatter and ensures a longer lifetime of the fuel cell.

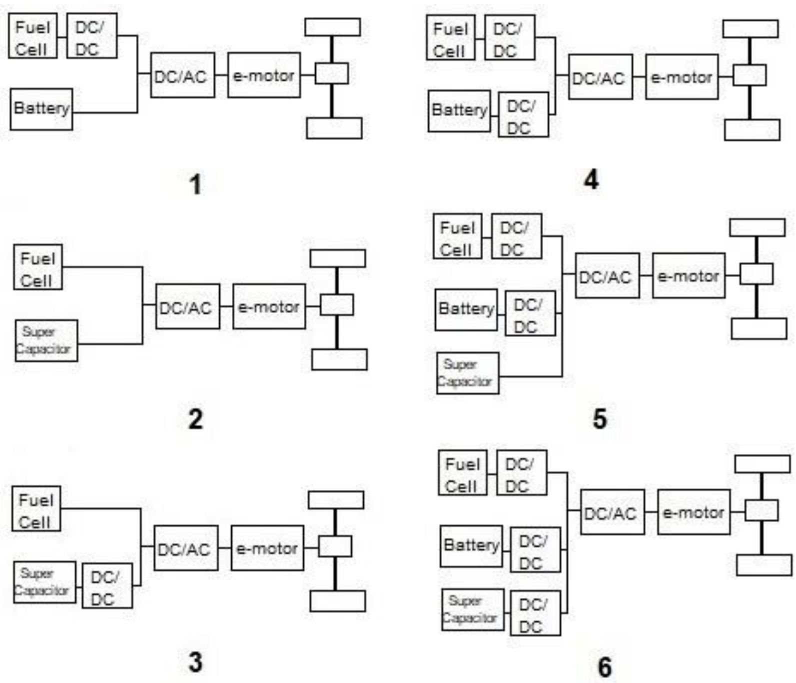


Figure 5. Fuel cell electric vehicle topologies (Xun et al., 2018; Teng et al., 2020)

6. Current Novelties

Since scientific research continues unabated, fuel cell innovations continue to emerge. Each of innovations in hydrogen technology improves the future of new mobility age. Future expectation of mobility is being seperated into battery electric for passenger cars and fuel cell electric for heavy-duty vehicles. Therefore, every single change in hydrogen systems affects mobility and fastens to meet environmental expectations. In order to show some of the recent innovations, publications, projects between 2021 and 2023 were reviewed and shared in table 6.

Table 6. Recent innovations on fuel cell technology

No	Content	Type	Reference
1	Circular sectional current collector investigation and flow channel comparison for SOFC	Article	(Ahmed and Ahmed, 2022)
2	Small scale manufacturing for fuel cell stack investigation and thermodynamic effectiveness	Article	(Taner, 2021)
3	Performance enhancer 4 different flow channels design and comparison	Article	(Gelis et al., 2022)
4	Continuous hydrogen production from ammonia for SOFC	Article	(Al-Hamed and Dincer, 2021)
5	Health monitoring of PEMFC by conversion between voltage signal and image	Article	(Liu et al., 2021)

6	Wind and solar supported hybrid fuel cell vehicle design and validation	Article	(Mamun et al., 2022)
7	Fuzzy logic control system for fuel cell longer life	Article	(Luca et al., 2022)
8	State of charge estimation of metal hydride by piezoelectric material	Article	(Chabane et al., 2022)
9	Grade and flow comparison of porous metal in fuel cell stack	Article	(Kermani et al., 2022)
10	Curvy flow line design and analysis for PEMFC	Article	(Rahmani et al., 2023)
11	Baffle shape comparison in flow channel of PEMFC	Article	(Huang et al., 2023)
12	Fluorinated carbon investigation to water management in PEFC	Article	(Can et al., 2022)
13	Humidifier design to overcome the drying problem by high air flow	Article	(Le et al., 2022)
14	Hydro-electricization of the shipping vehicles at the port of Valencia	Project	(Clean-Hydrogen, 2023; H2ports, 2023)
15	Hydro-powered 2 – 4 seats aircraft design.	Project	(Clean-Hydrogen, 2023; Heaven-fch-project, 2023)
16	Development of new electrolyser that combines the alkaline and polymer electrolyte water electrolysers.	Project	(Clean-Hydrogen, 2023; Newely, 2023)
17	Design of multi-mode usable SOFC as fuel cell and electrolyser	Project	(Clean-Hydrogen, 2023; Switch-fch, 2023)
18	40 ton fuel cell powered truck development	Project	(Forschung, 2023; Hydrogeneurope, 2023)
19	Developing a high active and long term stable catalyst for PEM	Project	(crescendo fuel cell, 2023; Immortal fuelcell, 2023)

7. Conclusion

Fuel Cell systems in electric vehicle promising green environment and so it is beneficial especially in heavy duty vehicles. When it comes to vehicle design, well-known battery electric vehicle systems are converted into fuel cell electric vehicles by adding fuel cell module. However transition process also has some negative resulted stages. Defining of critical sides of this promising system amplify the efficacy – reliability and it facilitates the design process and guides Research and Development processes. In this review, general problems, performance enhancer tips on fuel cell electric vehicles were reviewed in reference studies. Reviewed studies includes not only system based problems but also vehicle topology assessments. System performance can be in improved component based studies but this can not be sufficient in some cases. Therefore, vehicle topology studies are also included to expand the scope of the research. 36 problem-based fuel cell system performance enhancing tips, 5 special vehicle topology evaluations and 19 innovative studies on fuel cell technology were shared. The fuel cell is an evolving system and could have great potential with small improvements. Close examination of fuel cell systems was carried out and guiding signs for the improvement of the system were explained. The information disclosed in the review is intended to aid standardization for fuel cell electric vehicle studies. In fuel cell systems, temperature, humidity, material type, fuel cell stack and air velocity have been found to be factors that seriously affect performance. Besides variables, vehicle component placement has been found to be important in fuel cell systems as well as in battery electric vehicles. In the evaluation on the basis of settlement, the importance of the battery supporting supercapacitor and hydrogen storage was emphasized specifically.

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Statement of Conflict of Interest

The authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal

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